Revista Publicando, 5 No 16. (2). 2018, 119-131. ISSN 1390-9304

Investigate the Active Control of tall Building against Earthquake by considering Fuzzy Logic

Amir Hossein Shafiee [1], Ali Keyhani [1]

1. Department of Civil Engineering, Shahrood University of Technology, Shahrood, Iran, a.shafieehossein@gmail.com, ali.keuhani.shun@gmail.com

Abstract

Today, structural safety against natural disasters such as earthquake is one of the major concerns of structural engineers. In recent years, various methods have been proposed to retrofit structure which among them, structural control systems have been considered. Active control system is one of the effective systems for reducing the effects of earthquake and response structures, it's like that, this has been of great importance to the long – order process and creating high – rise building. The purpose of this study was to investigate the effect of fuzzy controller on the response of structures by presenting a numerical model related to a long structure by taking into account the fuzzy logic. After describing the structure equations of the study, the principles of the fuzzy controller are designed and then, using numerical model and taking into account the acceleration of different earthquakes, the structure response is compared and analyzed in different states. The results of the research show that the fuzzy controller provides a good performance in reducing the structure response and controlling it with a significant reduction in the volume of computations and the need for complex calculations.
Key words: Active control, Long structures, Fuzzy logic, Earthquake, Structure response

Received 19/08/2018
Approved 02/09/2018

1. Introduction

Protecting the structure, residents and equipment's against earthquake is always an important challenge in civil engineering. Today, this is a long process ranking and construction in seismic areas has become extremely important. In the past, design methods were considered based on non – elastic deformation, but today, structural control is of particular importance and in recent years a lot of research has been done on control of structures. There are various methods and systems for controlling structures that include active, semi – active, passive and compound control of structures [2]. Meanwhile, since the structural characteristics of passive systems are constant, then it is not able to change and adapt to the conditions, especially during an earthquake, so, it is necessary to pay more attention to the design of these systems. At the same time, these systems are less efficient and less capable than other systems due to lack of use of external power sources [12]. In addition, passive systems are only used for certain excitations that are designing and not very effective for other types of excitation, while active systems exhibit better performance against various excitations [1]. For this reason, after presenting this theme by Yao in 1972, a lot of research has been done in this regard and the first use of active systems in 1989 was the start of a practical application of active control of structures, which was further expanded [4]. Despite the extraordinary efficiency of active control, these systems are very complex and require high computing power. Moreover, data uncertainty (such as structural characteristics like mass, stiffness and damper, non – linear response of the structure, etc.) cannot be prevented. This makes it difficult to apply these systems in practice. Particularly the high computational volume prevents simultaneous calculations in the range of time. [7] The complexity of these systems and the behavior of structure due to uncertainty in structural parameters, which cannot be expressed by a precise model of structural behavior, in order to evaluate mathematical relations. Two simple but important factors of the high volume of computing and uncertainty of parameters have led the researchers to use fuzzy logic in the control of the structure. The basic idea of using fuzzy logic in controlling a structure is to use an operator instead of a complex mathematical model to control a system. In these systems, the structure has the ability to control its own behavior [1, 11]. In fuzzy control, verbal explanations are replaced by numerical values. This technique can reduce the operation volume and take into account the uncertainty of the parameters [5]. In the present study, the establishment of control force has been developed by using fuzzy systems as a control algorithm in the ATMD

Received 19/08/2018
Approved 02/09/2018

Revista Publicando, 5 No 16. (2). 2018, 119-131. ISSN 1390-9304

controller. In order to investigate the effect of the proposed method as a numerical study, an 11 – storey structure with ATMD is considered on the level of the roof. For this purpose, the fuzzy area controller was initially designed for a degree of freedom system, in the following design based on the maximum reduction of the structure response, a degree of freedom under the influence of a variety of near – field and far – field earthquakes was carried out. The system specification has a degree of freedom (mass, stiffness and damper) similar to that of the first mode of the 11 – storey structure selected, then the controller designed for the structure of a degree of freedom is used as the active mass damper controller in the structure. Finally, the responses of the proposed control method, the results of the uncontrolled structure, the structure controlled by TMD and the structures controlled by ATMD have been compared. The results of the research show that the fuzzy control algorithm, in addition to the highly effective method in comparison with other control algorithms in reducing the structure response, has a significant reduction in the volume of computational operations and the need for complex computations to desirable performance in reducing the structure response and controls it.

2. Modeling and Expression of Structural Differential Equations

Always, the first step in analyzing the structure is to provide differential governing equations on the structure and to find the values of structure response. So, the equation of the system of several degrees of freedom under control in real space is written as follows:

$$\mathrm{M}\,\ddot{u} + \mathrm{C}\,\dot{u} + K\,u = \mathrm{Du}(t) + Ef(t) \tag{1}$$

Where M, C, K, are mass, damper and stiffness matrix respectively and D, E are the place of control force and external stimulation matrixes. Also, u, ů, ü are N*1 vectors that represent the displacement, velocity and acceleration of classes. N is degree of system freedom, u is vector of control forces and f, shows an external excitation. In order to solve the matrix differential equations of structures, several methods have been proposed which among them, the use of state space method as one of the modern methods of solving differential equations is applicable [16].

For this purpose, the system equations in the state of space will be expressed as follows:

$$\dot{Z}(t) = A\,Z(t) + B\,\{eq\}$$

$$Z(0) = Z_0$$

Received 19/08/2018
Approved 02/09/2018

Revista Publicando, 5 No 16. (2). 2018, 119-131. ISSN 1390-9304

Where Z vector is a 2N*1vector and contains state space variables for solving differential equations, including the displacement and acceleration of classes and is expressed as follows:

$$Z = \begin{Bmatrix} \{u\} \\ \{\dot{u}\} \end{Bmatrix} \tag{2}$$

Finally, about an n – storey buildings, the differential equation of the structure is expressed as follows:

$$\dot{Z} = \begin{bmatrix} I_{n\times n} & O_{n\times n} \\ -[M]^{-1}[C] & -[M]^{-1}[K] \end{bmatrix} Z + \begin{bmatrix} O_{n\times n} \\ I_{n\times n} \end{bmatrix} \{eq\} \tag{3}$$

Where:

$$\{eq\} = -\{r\}\ddot{u}_g(t) \tag{4}$$

And{r} is (n*1) vector that the elements such as degree of freedom in line with earthquake acceleration is 1 and in other elements is 0. $\ddot{U}_g(t)$, shows earthquake at different times. Also, [0] is zero matrixes and [I] is unit matrix. By solving the desired system, the values of the matrix A and B can be defined as follows:

$$A = \begin{bmatrix} [0] & [I] \\ -M^{-1}K & -M^{-1}C \end{bmatrix} \tag{5}$$

$$B = \begin{bmatrix} O \\ I \end{bmatrix}$$

3. Fuzzy System Modeling

In general, the control system of a structure can be expressed in accordance with figure 1.

Received 19/08/2018
Approved 02/09/2018

Revista Publicando, 5 No 16. (2). 2018, 119-131. ISSN 1390-9304

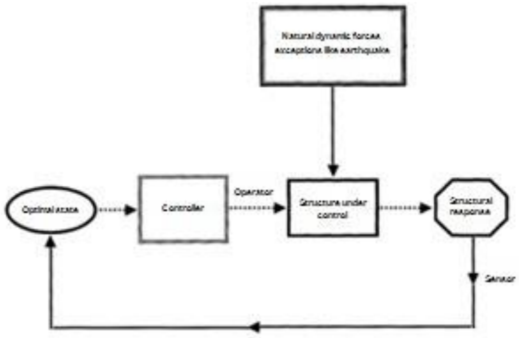


Figure 1. Fuzzy system modeling

In the following, we introduce different parts of a fuzzy model:

• Fuzzification: variables with real values are mapped to fuzzy sets.

• Fuzzy rule base: When the set of rules is fuzzy, that is a based on the knowledge of the expert.

• Inference system: This system combines the rules and creates a graph of the input to the output using the preceding and input operators; the fuzzy set is obtained as follows:

(6)

$$F^{j}(X)=\prod_{i=1}^{n}\mu_{F_i^j}(x_j)$$

• Defuzification: The output of the fuzzy inference system is the fuzzy values which apply to the system; they must be come in the form of definite and non- fuzzy numbers and values that is done by defuzzification. In many control issues, the system model is unknown or the input parameters vary in size. In these cases, fuzzy controllers can be used because of the ability to determine the outputs for a set of inputs without using conventional math models. In addition to less sensitivity to change variables, these controllers lead to a greater understanding of the control system due to the use of common language phrases and certified decision making methods.

4. Modeling and Designing Fuzzy Controller

In general, Fuzzy controller modeling and design are based on the information received from the structure. This absolute information is mapped to fuzzy sets by the fuzzification process. In this research, fuzzy controller is designed with using two input variables (velocity and structural change of a degree of freedom) and output variable (control force in ATMD). Each of the input variables has 3 up and down triangular membership functions and the output variable has 7 upper and lower single membership functions. The membership functions of the

Received 19/08/2018
Approved 02/09/2018

Revista Publicando, 5 No 16. (2). 2018, 119-131. ISSN 1390-9304

input and output variables can be seen in figures 2 and 3, respectively. The variables used to develop fuzzy space are given in table 1.

Table1. Inference rules used in fuzzy control

Membership function	Variables	Definition
Input	Positive	P
	Zero	Z
	Negative	N
Output	Positive Big	PB
	Positive Medium	PM
	Positive Small	PS
	Zero	Z
	Negative Small	NS
	Negative Medium	NM
	Negative Big	NB

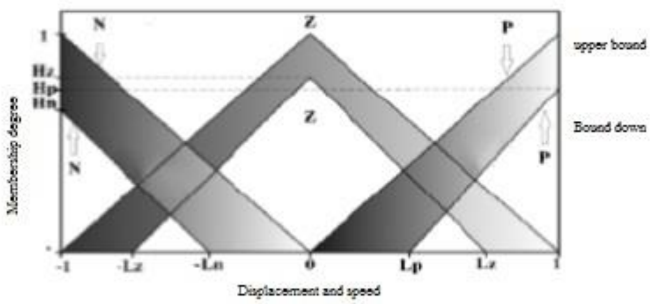


Figure 2. The membership function associated with the input variables

Received 19/08/2018
Approved 02/09/2018

Revista Publicando, 5 No 16. (2). 2018, 119-131. ISSN 1390-9304

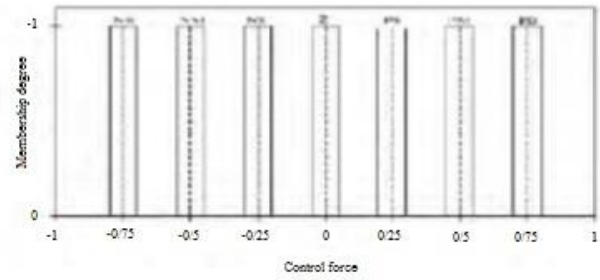


Figure 3. The membership function associated with the output variables

In the present study, the membership function associated with the variables Fuzzy according to table 2. Also, in the present study, the Mamadani inference method in the modeling and design of fuzzy controller have been used.

Table2. Fuzzy variables

	Velocity		
Displacement	**P**	**Z**	**N**
N	**PS**	**PM**	**PB**
Z	**NS**	**Z**	**PS**
P	**NB**	**NM**	**NS**

5. Numerical Study

In order to investigate the effect of the fuzzy control model on reducing the structure response, an 11 – storey construction has been used and the structure is simulated by the acceleration of various earthquakes. The international committee for structural control has identified 4 earthquake accelerograms for seismic applications regarding the impact of proposed control methods that among them, the accelerograms of far – field section (Elsentro) and the near field section (Kobe and Northridge) are suggested. The maximum absolute acceleration of these accelerograms for earthquakes in Elsentro, Kobe and Northridge is equal to PGA=%3417, PGA= %8267, PGA= %8178g respectively. In this study, we used 3 accelerograms with scaled intensities for investigate the effect of fuzzy control. Given the similarity between them, the results of the Elsentro earthquake as a far field and Kobe earthquake as a near field are presented [19]. In the first step of the numerical example, the fuzzy controller for the system

Received 19/08/2018
Approved 02/09/2018

Revista Publicando, 5 No 16. (2). 2018, 119-131. ISSN 1390-9304

of degree of freedom is modeled and designed with the specification of the first mode of the 11 – storey construction. Specifications relating to the modeling of a degree of freedom of the structure and mass – damper are shown in table 3.

Table3. System specification of degree of freedom and mass damper

	Mass (kg)	Stiffness (N/m)	Damping (%)
Degree of freedom	**1/05 e6**	**5/14 e7**	**5**
Mass damper	**62190**	**3029140**	**7**

The reasons for choosing a degree of freedom system for fuzzy controller modeling can be considered in the very good approximation of the structural first mode, easy modeling and low computational cost. Maximum displacement of the system of a degree of freedom under the influence of the above earthquakes, along with the maximum reduction of response in different control modes can be seen in table4.

Table4. Maximum displacement of the system's degree of freedom response

Earthquake	Maximum displacement of the system degree of freedom (m)			Maximum reduction response (%)	
	Uncontrolled	ATMD	Fuzzy	ATMD	Fuzzy
Elsentro	**0/08**	**0/06**	**0/04**	**19**	**39**
Kobe	**0/14**	**0/11**	**0/08**	**18**	**43**

By examining the results, it can be seen that a fuzzy controller modeled in ATMD is very effective in reducing the system response to a degree of freedom. Perhaps, the most important factor of fuzzy controller superiority than other methods is to reduce the structure response in terms of uncertainty in fuzzy rules. The information used to construct fuzzy rules is uncertain. Uncertainty in fuzzy rules is created for a variety of reasons. For example, if expert questions are asked about how to select parameters related to input membership functions (velocity and displacement) and output (control force), different answers will be received. This indicates the existence of uncertainty in the fuzzy sets of input and output variables. Similarly, the response of different professionals to a constant question is different. This means that there are different sections for a fixed antecedent section. Uncertainty can be caused by other factors such as earthquake excitation. The response received by the sensors can be accompanied with

Received 19/08/2018
Approved 02/09/2018

Revista Publicando, 5 No 16. (2). 2018, 119-131. ISSN 1390-9304

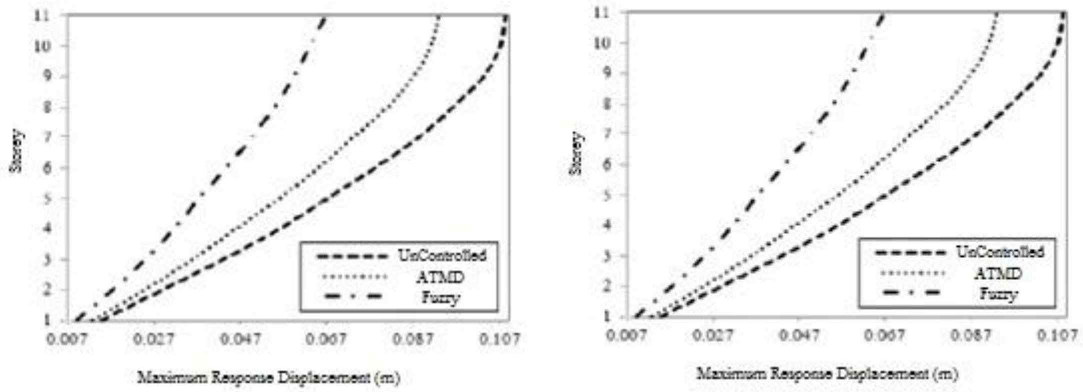
disturbances during an earthquake, and the response from the structure to the controller is not accurate. This type of uncertainty can also be easily considered by modeling in the fuzzy controller. In the second step of the numerical example, the fuzzy controller for a system of a degree of freedom is used as ATMD controller in the 11 – storey of construction. Specification of the 11 – storey structure can be found in table 5.

Table 5. The 11 – storey parameters

Storey	Mass (kg)	Stiffness (N/m)
1	215370	4/68 e8
2	201750	4/76 e8
3	201750	4/68 e8
4	200930	4/50 e8
5	200930	4/50 e8
6	200930	4/50 e8
7	203180	4/50 e8
8	202910	4/37 e8
9	202910	4/37 e8
10	176100	4/37 e8
11	66230	3/12 e8

The maximum displacement of classes in different states of control for earthquakes can be seen in figure4. These displacements, along with the values for maximum response reduction in classes for earthquakes and different control systems have been considered. According to the results obtained, it can be seen that the fuzzy controller significantly reduces the maximum displacement in the roof floor for Elsentro and Kobe earthquakes.

Received 19/08/2018
Approved 02/09/2018



a. Elsentro earthquake **b. Kobe** earthquake

Figure5. Maximum uncontrolled and controlled displacement of floors related to the 11 – storey structure. a. Elsentro, b. Kobe

6. Conclusion

By studying the research on controlling structures with ATMD activated mass damper, it can be seen that a certain numerical study has not been done so far in relation to the modeling and application of fuzzy systems as a control algorithm, for creating control force in ATMD. In the present study, application of the above mentioned systems in an active mass damper has been studied to reduce the structure response. For this purpose, in order to evaluate the efficiency of the proposed control model, the controller designed for the system of degrees of freedom as an ATMD controller in the 11 – storey structure is considered and the results obtained are as follows:

• Fuzzy controller has a significant effect on reducing the response of structures in comparison with other methods, with a significant reduction in the volume of computational operations. Also, the controller modeling and its design for the system of degree of freedom, with the specification of the first mode of the 11 – storey structure, have a very significant reduction in the actual structure response. On the other hand, as shown in the corresponding diagrams, active control can greatly reduce the structure response.

• The active control in fuzzy mode controls the structure response very well and in many cases even better than controlled mode act. What has been achieved by comparing the results is the significant effect of using fuzzy logic on an active control of structures in obtaining the values of responses which significantly reduces these values.

Received 19/08/2018
Approved 02/09/2018

• The comparison between the fuzzy controlled method shows that the fuzzy method has the ability to reduce the structure response even in controlled state. The advantage of this method is that it can take into account uncertainty in structural parameters and reduce the volume of computations in such a way that the use of complex control methods will no longer be needed. The only problem with the use of fuzzy method is the change in the knowledge base by changing the target function, which is monitoring this method is a bit more difficult than the controlled method, while in the controlled method, it is easy to control the parameters of the structure responses.

7. References

[1] Akutagawa, S., Otsuki, M., Kitagawa, Y., “Hybrid control system with optimal fuzzy logic and genetic algorithm for high-rise buildings”, 13th World Conference on Earthquake Engineering, Vancouver, B.C., Canada, 2004.

[2] Housner, G.W., Bergman, L.A., Caughey, T.K., Chassiakos, A.G., Claus, R.O., Masri, S.F., et. al., “Structural control: past, present and future”, J. of Eng. Mech., Vol. 123(9), pp. 897-971, 1997.

[3] Park, K.S., Koh, H.M., Seo, C.W., “Independent modal space fuzzy control of Earthquake-excited structures”, J. of Eng. Struct., Vol.26, pp. 279-289, 2004.

[4] Kobori, T., Koshika, N., Yamada, K., Ikeda, Y., “Seismic-response-controlled Structure with active mass driver system. Part II: verification”, Earthquake Eng. Struct. Dynamic. , Vol. 20(20), pp. 151-166, 1991.

[5] McLauchlan, R. A., et. al., “Active vibration control of a Multi-DOF structure by the use of fuzzy gain scheduling of PID controller under varying wind and earthquake shear force”, Texas A&M University, 2001.

[6] Kirk, D.E., “Optimal control theory”, Prentice-Hall, NJ, USA, 1974.

Received 19/08/2018
Approved 02/09/2018

[7] Qiu, S., Scherer, R.J., “Construction of an active control system for seismically Excited structures using fuzzy logic techniques”, 13th World Conference on Earthquake Engineering, Vancouver, B.C., Canada, 2004.

[8] Soong, T.T., “Active structural control, theory and practice”, John Willy & Sons Inc., New York, 1989.

[9] Shook, D., Tani, A., Kawamura, H., Roschke, P., “Hybrid control of structures Utilizing fuzzy logic and genetic algorithm”, Univ. of Kobe, Japan, 2003.

[10] Ross, T.J., “Fuzzy logic with engineering applications”, McGraw-Hill Inc., Singapore, 1997.

[11] Tang, J., Shoaee, H., “A comparative study of fuzzy logic and classical control with EPICS”, Newport News, VA, USA, 1995.

[12] Wongprasert, N., Symans, M.D., “Application of genetic algorithm for optimal Damper distribution within nonlinear seismic benchmark building”, J. of Eng. Mech., ASCE, Vol. 130(4), pp. 401-406, 2004.

[13] Rana, A. and Dubey, S.K., “A Fuzzy Approach for Evaluation of Maintainability of Object Oriented Software System”, International Journal of Computer Applications, vol.41, issue no. 29, pp. 0975 - 8887, 2012.

[14] Yano, K., Tani, A., Kawamura, H., Takizawa, A., “Shaking table tests on intelligent fuzzy optimal active control system of building structures adapting to vibration mode”, 13thWorld Conference on Earthquake Engineering, Vancouver, B.C., Canada, 2004.

[15] Mahdi Fakoor, Amirreza Kosari, Mohsen Jafarzadeh, Humanoid robot path planning with fuzzy Markov decision processes, Journal of Applied Research and Technology, Available online 21 August 2016.

Received 19/08/2018
Approved 02/09/2018

[16] Ogata, K., "Modern Control Engineering", Engle wood Cliffs, N.J. Prentice Hall Inc., 2010.

[17] Hartog, J.P., Mechanical vibrations, McGraw-Hill: New York, 2013.

[18] Haack, S., Philosophy of logic, Cambridge University Press, 152-153, 2012.

[19] Samali, B., Al-Dawod, M. (2003), "Performance of a five-storey benchmark model using an active tuned mass damper and a fuzzy controller". Eng. Struc, Vol. 25, pp. 1597-1610.

Received 19/08/2018
Approved 02/09/2018